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Summary

Within the political, scientific and economic debate on climate change, the process of evaluating climate policies ex-ante, during and/or ex-post their lifetime, is receiving increasing attention from international institutions and organisations. The task becomes particularly challenging when the aim is to evaluate strategies or policies from a sustainability perspective. The three pillars of sustainability should then be jointly considered in the evaluation process, thus enabling a comparison of the social, the environmental and the economic dimensions of the policy's impact. This is commonly done in a qualitative manner and is often based on subjective procedures. The present paper discusses a data-based, quantitative methodology to assess the relative performances of different climate policies, when long term economic, social and environmental impacts of the policy are considered. The methodology computes competitive advantages as well as relative efficiencies of climate policies and is here presented through an application to a sample of eleven global climate policies, considered as plausible for the near future. The proposed procedure is based on Data Envelopment Analysis (DEA), a technique commonly employed in evaluating the relative efficiency of a set of decision making units. We consider here two possible applications of DEA. In the first, DEA is applied coupled with Cost-Benefit Analysis (CBA) in order to evaluate the comparative advantages of policies when accounting for social and environmental impacts, as well as net economic benefits. In the second, DEA is applied to compute a relative efficiency score, which accounts for environmental and social benefits and costs interpreted as outputs and inputs. Although the choice of the model used to simulate future economic and environmental implications of each policy (in the present paper we use the FEEM RICE model), as well as the choice of indicators for costs and benefits, represent both arbitrary decisions, the methodology presented is shown to represent a practical tool to be flexibly adopted by decision makers in the phase of policy design.

Keywords: Climate, Policy, Valuation, Data envelopment analysis, Sustainability

JEL Classification: H41, Q51, Q54, C61

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1. Introduction

Recent developments in climate change control have given an indication of how important it is to be accurate in measuring the efficiency of efforts towards climate control. In the past, the usual way of planning climate policy has led to a certain deadlock in negotiations. Indeed, even though the Kyoto Protocol came into force on February 16th, its environmental effectiveness is very low due to the lack of participation of several key countries. In particular the world's largest producer of GHG emissions, the US, has decided not only to remain outside the Kyoto framework, but has also announced a weak alternative climate change policy. The US decision has affected the participation incentives of various countries, as is for example shown by Australia's postponement of the ratification and Russia's hesitation to take a final position on the Kyoto Protocol. Only recently, in November 2004, did Russia finally ratified the treaty after a long period of contradictory announcements that had hindered the Kyoto Protocol's coming into force. In addition, in order to implement an approach towards a successful long-term strategy to halt the threat of climate change, developing countries also need to be included in the strategy.

The US decision not to ratify Kyoto and its implications have thus clearly weakened the Kyoto Protocol and undermined its environmental effectiveness. At the same time, general consensus has emerged that the Kyoto Protocol represents only a first step towards the broader aim of minimising the danger of climate change. Climate change can only be effectively defeated if a large number of countries, including the major CO2-emitters, co-ordinate their efforts to reduce GHG emissions. In addition, the Protocol contains commitments only through 2012, thus implying that new negotiations on a Beyond-2012 phase will soon become necessary. Yet, given the difficulty of measuring climate policies in a satisfactory way, no strategy that can satisfy all the needs of all countries has yet been identified. This problem is becoming more pressing because of the increasing urgency to improve the credibility of climate policy in general. Indeed, in order to move forward in climate negotiations, countries need to have a better way of evaluating efforts at their disposal. Two particular reasons stress the importance of such an evaluation tool. First, the US needs to have instruments to evaluate its next steps in climate policy and not to lose face given its past strategy. Second, the general stalemate in the Kyoto negotiations suggests that all countries would benefit from a new approach to looking at climate change measures. Above all, focussing exclusively on emissions or emission concentrations or temperature appears to be too narrow[1]. We need to move beyond this perspective in order to evaluate the efficiency of climate change control more comprehensively. In particular, given the international commitment towards sustainable development as

[1] Indeed, an increase in recent research efforts emphasises the need to go beyond traditional CO2 concentration stabilisation exercises (see e.g., Sarofim et al., 2004; Kemfert at al., 2004; Richels et al., 2004; Tol, 2004).

the overall guideline for all areas of policy making[2], measurements of efficiency better able to account for the three dimensions of sustainability – i.e., the economic, social and environmental aspects – are essential if climate-energy policy is to be more effective and successful.

Let us start by providing an overview of the debate related to the design of, and motivations behind, climate policies. During the last few decades, climate change has clearly evolved as one of the major threats to the earth's sustainability. The political response in the form of the United Nations Framework Convention on Climate Change (UNFCCC) and more specifically the Kyoto Protocol have started a process towards a new climate architecture better able to cope with the complexities of climate change. However, given the difficulties of finding an agreement on international climate change efforts – in particular the current stalemate in including the major players in the negotiations on the Kyoto Protocol – and the continued spiralling increases in the global emission of greenhouse gases, the future of climate policy is still characterised by uncertainties. This has stimulated detailed discussions on potential climate policy scenarios and a number of different approaches have been applied in order to analyse the possible future of climate policy.

On the one hand, research has generally tried to focus on searching for participation incentives in international environmental agreements. More specifically, the main research objective is to identify policy strategies and policy architectures (i.e. the design of an international climate agreement) that provide adequate incentives for the participation of most world countries in the cooperative effort to control GHG emissions. In this context, see, for example, Aldy, Barrett and Stavins (2003) for a survey of climate policy architectures; Buchner and Carraro (2003; 2004a,b) for a discussion of various participation incentives and Jacoby et al. (1999) for an identification of key architectural features. On the other hand, a large number of more focussed research studies have tried to explore what type of emission reduction commitments should be adopted by participating countries after the first commitment period of the Kyoto Protocol, thus looking beyond 2012. In this strand of literature, see, for example, Baumert et al. (2002) for a collection of articles on possibilities for shaping an international climate change agreement, Berk et al. (2001) and den Elzen et al. (2003) for the analysis of different future climate regimes, Pershing and Tudela (2003) on ideas to establish more concrete long-term climate goals, or Torvanger et al. (2004) for a broad survey of current literature. In addition, there have been some recent attempts to link these two approaches, i.e. to highlight both the economic and environmental consequences of different scenarios on beyond Kyoto commitments and the implications of these commitments for providing

[2] See, for example, the Johannesburg Declaration on Sustainable Development that was adopted at the World Summit on Sustainable Development held in Johannesburg, South Africa, from 2 to 4 September 2002. This statement reaffirms the world's commitment to sustainable development.

incentives for countries to participate (see e.g. Buchner and Carraro, 2005). The climate policy scenarios embedded in most of the policy proposals usually represent mitigation scenarios that are defined through a description and a quantified projection of how GHG emissions can be reduced with respect to some baseline scenario and/or how a specific GHG target can be achieved in order to stabilise atmospheric concentrations. They contain new emission profiles as well as costs and benefits associated with emission reductions. In order to do so, and once the first design phase is over, policies are simulated using economic-climate models in order to forecast the potential long-term effects on relevant variables, such as the implied increase in global atmospheric temperature or the effect on GDP growth. By means of such simulations, a comparison of different climate policies should be possible.

Still, given the prevailing uncertainties, an accurate evaluation and thus comparison of climate policy proposals is difficult. Therefore, the objective of this paper is not solely to discuss and comment on different policies or policy portfolios, but is primarily to extract useful information in the phase where proposed and simulated climate policy scenarios are compared. For this purpose, we apply the Data Envelopment Analysis (DEA), a methodology which is technically closely related to Multi-Criteria Analysis, in that it allows us to deal with situations where multiple inputs and outputs occur. In particular, we are interested in incorporating the economic, the environmental and the social dimensions of the positive and negative impacts of each policy scenario, in order to bridge the gap between the simulation phase, in which long-run effects of policies are mimicked, and the valuation phase, in which usually a coherent cost benefit analysis framework is adopted. These phases culminate with a useful set of information which provide feedback into the process of designing policies.

DEA uses data observations to directly evaluate the relative performance of a set of decision making units, in a multi input–multi output context. At first, it was mainly developed to evaluate the relative efficiency of firms by transforming multiple inputs into multiple outputs, making minimal prior assumptions about the shape of the production possibility set, but inferring information from the data set. While the conventional definition of efficiency can be traced back to Farrell (1957), the first publication that made the DEA methodology popular and introduced it into the operation research world was Charnes *et al.* (1978). Subsequently, DEA has been applied to evaluate the relative performance of medical services, as in Nyman and Bricker (1989), or of educational institutions, as in Charnes *et al.* (1981). It has also been applied in the private sector, as in the valuation of banks, in Charnes *et al.* (1990). A thorough review of the theory and applications related to DEA can be found in Coelli *et al.* (1998), while an extensive bibliography is reported in the survey articles by Seiford (1996) and Taveres (2002). Applications to environmental and resource management problems are less frequent. In general, environmental and social impacts can be modelled as undesirable outputs or as conventional inputs. The absence of market prices for these undesirable outputs, which is a generally recognised valuation problem, can be overcome by employing DEA. Some studies have applied DEA in measuring ecological efficiency (e.g. Dyckhoff and Allen, 2001); some others in measuring the environmental impact of different production technologies, as for example De Koeijer, et al. (2002), where the impact of different production techniques in the farm industry are compared. Bosetti and Locatelli (2003) consider the economic and environmental dimensions of management performances of National Parks, while Hernandez-Sancho *et al.* (2000) consider the issue of efficiency in environmental regulation. An interesting overview of the role of DEA in environmental valuation can be found in Kortelainen and Kuosmanen (2004), while a survey of indicators of firms' environmental behaviour can be found in Tyteca (1996). Ferrier and Hirschberg (1992) have applied DEA to the assessment of energy efficiency in buildings.

However, to the authors' knowledge, DEA has not yet been applied in the comparative assessment of (climate) policies. For this reason, the main objective of this paper is to use a fairly straightforward exercise to show an application of this technique in the valuation of different climate policies, in order to provide decision makers with an additional tool of analysis.

The rest of the paper is organised as follows. Section 2 introduces the methodological framework describing, on one hand, the FEEM-RICE model which is adopted to simulate long-run effects of the different policies, and on the other hand, the Data Envelopment Analysis (DEA) methodology, which is then applied to compare the various policy scenarios. In particular, the choice of cost and benefit indicators for each policy is introduced and discussed. Section 3 provides a detailed overview of the policy scenarios that are the subject of this analysis. Both the features of the policy proposals and their underlying motivations are tackled. Finally, Section 4 discusses the results and provides conclusions as well as indications for further future research.

2. Methodology

Our analysis is based on a hybrid methodology, which couples a traditional simulation analysis - performed in our case by means of a top-down optimal growth economic-climate model, the FEEM-RICE model - with a relative efficiency valuation technique, namely the DEA. We apply this methodology in order to compare a set of policy scenarios. These scenarios either stem from political feasibility considerations or from scientific concerns regarding unconstrained global warming, or from a combination of the two. The motivations for the policy scenarios in consideration are discussed in greater detail in the subsequent section. We shall now focus on the methodological issues.

Let us start by considering the simulation phase. Scenarios are simulated using the FEEM-RICE model, a multi-region optimal growth model developed out of Nordhaus and Boyer's RICE 99. The FEEM-RICE mainly differs from the original model in the treatment of endogenous technical change (for a detailed discussion see Bosetti, Carraro, Galeotti 2004) and in the way the optimal solution is computed (see Buonanno *et al.*, 2000). Specifically, in FEEM-RICE each region plays a non-cooperative Nash game in a dynamic setting which yields an Open Loop Nash equilibrium. This is a situation where in each region central planners maximise their utility subject to the individual resource and capital constraints and the climate module for a given emission production of all the other players. Kyoto-type international environmental agreements can be easily accommodated by adding a constraint according to which regional emissions cannot exceed a given upper limit. It is also possible to account for international emission trading in the model simulation: in this case the standard identity between sources and uses of resources specifies that output be used for consumption and investment, to which proceeds or sales from net imports of permits should be added. In the case of permit trading, a region's emissions may exceed the limit set in Kyoto if permits are bought, and vice versa in the case of permit sales. Finally, in the FEEM-RICE model, the evolution of technology is endogenised. In particular, by including learning by doing and learning by researching, the two main driving forces of technological change are modelled. These two factors affect emissions in two ways: through the energy intensity relationship and through the carbon intensity relationship. Data on carbon emissions, which arise as output from the economic module, enter a three box climate module that produces data on temperature increase, which in turn feeds back into the economic module through a damage function. The presence of a climate module makes it straightforward to implement scenarios characterised by a long-term stabilisation target, as a cap on atmospheric carbon concentration or radiative forcing.

The model simulates a set of climate policies which provide the ingredients for analysis in the subsequent comparison phase. Each simulated policy is evaluated through a multi-dimensional scoring vector, accounting for its economic, social and environmental performances. The choice of indicators may depend on what features one would like to emphasise and/or on what features are accounted for in the simulation model. As an example, the FEEM.-RICE model accounts for endogenous technology learning processes and an indicator of expenditure in R&D is available. In addition, the regional level of aggregation provides information on the distribution across the world of positive and negative impacts, obviously neglected in world aggregate models, while the issue of uneven distribution is recognised as one of the most problematic features of the climate change issue. Conversely, other models include a more detailed description of the different environmental impacts of climate change.[3]

Whatever the chosen vector of information, it is not always univocally possible to assess which is the most promising policy, unless one weakly dominates all the others (i.e. a policy is superior in at least one dimension without being inferior in any of the remaining dimensions). This depends on the fact that there does not exist a straightforward way of aggregating different impacts, which are typically expressed in

[3] For example, information on sea-level increases can be included in the analysis. See Roson et al. (2004).

different units. The DEA approach overcomes the problem of incommensurability by solving a linear programming problem, whose decision variables are the aggregating weights. Note that DEA is extended from its traditional application, namely the evaluation of production firms' performances, to evaluating the performance of policies. Thus, terms such as inputs and outputs, traditionally adopted in the DEA framework, have to be understood here in a broader sense as indicators of costs (or whatever indicators for which lower values are preferred) and indicators of benefits. In particular, we consider two possible approaches that differ mainly according to whether the emphasis is on assessing comparative advantages or a relative efficiency score. The first consists of linking the DEA to a CBA analysis. While the economic impact of each policy is expressed in terms of discounted net monetary value, social and environmental impacts are expressed in their own unitary measures. DEA is applied in order to obtain a comparative advantage measure for each policy, estimating weights, or prices for the non-monetary indicators that ought to be included in the valuation. The second approach is a more straightforward application of the traditional DEA, aiming at the computation of a relative efficiency measure for each policy. The efficiency measure is established mathematically by the ratio of the weighted sum of output to the weighted sum of input. In particular, a policy is 100 percent efficient if and only if:

- none of its output can be increased without either increasing one or more of its inputs, or decreasing some of its other outputs;
- none of its inputs can be decreased without either decreasing some of its outputs or increasing some of its other inputs.

DEA-based Cost Benefit Analysis.

Let us consider the first approach. Each scenario is identified through a set of economic indices. In our example, global discounted production and global discounted R&D expenditures are considered, both computed over the years 1995-2105 and expressed in trillions of 1990 USD. These two economic indices are aggregated in a discounted net economic value of each policy, NE_m for the m-th policy scenario. Each scenario, m, is also characterised by a social impact indicator, $Z_{s,m}$ and an environmental impact indicator, $Z_{e,m}$. Again, in our example, to account for a social perspective, each of the scenarios is valued for its impact on the welfare wedge between regions of the world, measured using an equity index. The computation of the equity index follows the approach proposed by Bosello and Roson (1999) and is built on the comparison of an "equity distributed level of consumption" with the actual average consumption per capita. Finally, in order to account for the environmental impact of each policy, several alternative measures could be adopted. For example, carbon or GHGs emissions, carbon or GHGs atmospheric concentrations, increase in radiative forcing or in temperature or total damage, which may be expressed in physical or monetary terms. Each measure represents a different stage of the climate cycle. In the present analysis, the increase in global temperature is chosen as the indicator for environmental impact. The reason for this choice is that it coincides conveniently with the climate policy target (compared to, for instance, carbon atmospheric concentrations) and at the same time does not interfere with the still unresolved debate concerning impact on climate and its evaluation. The environmental impact index is expressed in temperature increases above pre-industrial levels in deg C.

The set of indicators used in the first analysis is summarised in Table 2 and values for each indicator are depicted in Figures 1-4.

The total benefit, TB_m of policy m can be expressed as the difference between net discounted economic value and environmental and social impacts, more formally:

$$TB_m = NE_m - p_e Z_{e,m} - p_s Z_{s,m} \tag{1}$$

where p_e and p_s are the weights (prices) associated to the environmental and social indices. As discussed in Kortelainen and Kuosmanen (2004), we can consider the problem from a game-theoretic perspective and suppose that each defendant of a particular policy can adopt a strategic opportunistic behaviour and consider[4] the price vector, **p**, which maximises the advantages of the proposed policy, over the others. In practice, this consists of solving, for each policy m, the problem of choosing a non negative price vector that maximises that policy's Comparative Advantage (CA_m), given the other policies. More formally, it consists of solving, for each of the analysed policies, $m \in M$, the following linear programming problem:

$$\begin{aligned}
&\max_{p_e, p_s} CA_m \\
&s.t. \\
&CA_m \le \left[NB_m - p_e Z_{e,m} - p_s Z_{s,m}\right] - \left[NB_1 - p_e Z_{e,1} - p_s Z_{s,1}\right] \\
&CA_m \le \left[NB_m - p_e Z_{e,m} - p_s Z_{s,m}\right] - \left[NB_2 - p_e Z_{e,2} - p_s Z_{s,2}\right] \\
&\vdots \\
&CA_m \le \left[NB_m - p_e Z_{e,m} - p_s Z_{s,m}\right] - \left[NB_{m-1} - p_e Z_{e,m-1} - p_s Z_{s,m-1}\right] \\
&CA_m \le \left[NB_m - p_e Z_{e,m} - p_s Z_{s,m}\right] - \left[NB_{m+1} - p_e Z_{e,m+1} - p_s Z_{s,m+1}\right] \\
&\vdots \\
&CA_m \le \left[NB_m - p_e Z_{e,m} - p_s Z_{s,m}\right] - \left[NB_M - p_e Z_{e,M} - p_s Z_{s,M}\right] \\
&NB_m - p_e Z_{e,m} - p_s Z_{s,m} \ge 0 \\
&p_e, p_s \ge 0
\end{aligned} \tag{2}$$

[4] On the basis of results of valuation studies, opportunely and opportunistically manipulated.

When the m-th policy turns out not to have any comparative advantage over the others, $CA_m < 0$, even allowing for the choice of the most convenient prices vector, then it is clear that the policy should be rejected. Contrariwise, for policies showing a non-negative comparative advantage over other policies $CA_m \geq 0$, a sensitivity analysis on prices can be performed in order to have a better understanding of the results. The process can be enhanced by interfacing the discussion concerning the domain of weights to the political debate, thus enabling policy makers to gain a better understanding of how to interpret analysis results.

DEA relative efficiency computation.

The second approach involves the computation of efficiency scores based on the comparison of each policy with the others in the sample. A maximum score of unity (or 100%) is considered as the benchmark. Indicators are now reinterpreted in terms of inputs (costs) and outputs (benefits). On the input side, economic, environmental and social costs can be considered. In our example, we consider global discounted R&D expenditures as an economic cost indicator, computed over years 1995-2105 and expressed in trillions of 1990 USD. Global atmospheric temperature increases serve as an environmental impact indicator. Instead, on the output side, we consider global discounted output and global welfare (defined as the present value of per capita consumption) to be benefits, both computed over years 1995-2105 and expressed in trillion of 1990 USD. Social benefits are accounted for through the equity index (computed as above). The set of indicators used in the second analysis is summarised in Table 3, and is identical to that used in the previous exercise but for one indicator, whose values are depicted in Figure 5. The efficiency score of each policy is expressed as the ratio of the weighted sum of outputs over the weighted sum of inputs. For each policy, a set of weights is chosen such that it maximises its efficiency. More formally, given the set of M policies, each with J outputs (benefits) given a set of I inputs (costs), let us denote by y_{jm} and x_{im} the vectors representing the quantities of outputs and inputs relative to the m-th DMU, respectively. The efficiency of the m-th policy can thus be calculated as:

$$(3) \qquad e_m = \frac{\sum_{j=1}^{J} u_j y_{jm}}{\sum_{i=1}^{I} v_i x_{im}}, \qquad \begin{bmatrix} j = 1,..,J \\ i = 1,..,I \end{bmatrix}$$

where u_j and v_i are two vectors of weights used in the measurement of policy m's relative importance of inputs and outputs calculated through the maximisation problem, which is stated below for policy m:

$$
\max_{u_j, v_i} e_m
$$

$$
s.t.
$$

(4) $$\frac{\sum_{j=1}^{J} u_j y_{jn}}{\sum_{i=1}^{I} v_i x_{in}} \le 1 \quad \forall n = 1,.,m,.,M$$

$$
0 \le u_j \le 1
$$

$$
0 \le v_i \le 1
$$

To simplify computations it is possible to scale the input prices so that the cost of the DMU m's inputs is equal to 1, thus transforming the problem set in (4) into the ordinary linear programming problem stated below:

$$
\max h_m = \sum_{j=1}^{J} u_j y_{jm}
$$

$$
s.t.
$$

(5) $$\sum_{i=1}^{I} v_i x_{im} = 1$$

$$
\sum_{j=1}^{J} u_j y_{jn} - \sum_{i=1}^{I} v_i x_{in} \le 0 \quad \forall n = 1,.,m,.,M
$$

$$
\varepsilon \le u_j \le 1, \ \varepsilon \le v_i \le 1, \ \varepsilon \in \Re^+
$$

In addition to the linearisation constraint, weights must be fixed at strictly positive values (greater than or equal to a very small quantity epsilon) so that no inputs or outputs are ignored in the process of determining the efficiency of each policy.

If the solution to the maximisation problem gives a value of efficiency equal to 100, the corresponding scenario is considered to be efficient or non-dominated; if instead the efficiency value is inferior to 100, then the corresponding scenario is said to be dominated, and therefore does not lie on the efficiency frontier, which is defined by the envelopment of efficient scenarios. Furthermore, information concerning potential improvements of inefficient policies can be obtained.

3. Eleven Climate Policy Scenarios

Based on the above methodological framework, a number of policy scenarios can be evaluated. This section will introduce the policy scenarios that have been chosen for our analysis, and the relevant policy framework will be described. In total, we have designed ten scenarios on the basis of indications from policy processes and the scientific community. The resulting scenarios are particularly relevant for potential considerations of future climate policy. In addition to these policy scenarios, we provide as a **first scenario** a business-as-usual projection in order to have a credible benchmark for our evaluation. The BAU scenario is characterised by a continuation of the current trends in the main economic and environmental parameters.

The remaining ten policy scenarios possess some common features. In particular, all scenarios assume that the absolute emission reductions defined in the Kyoto Protocol will be achieved by the Annex B_{-US} countries[5] by 2010 (first commitment period). Indeed, it was Russia's ratification of the Kyoto Protocol on November 4[6], 2004 that opened the way for the Protocol's coming into force on February 16, 2005.[7] The Protocol makes the emissions targets taken on for the 2008-2012 period by more than 30 developed countries (including the EU, Russia, Japan, Canada, New Zealand, Norway and Switzerland) legally binding. The US is assumed to achieve its –18% emission intensity target in order to slow the growth of GHG emissions per unit of economic activity over the next 10 years[8]. Developing countries have no target in the first commitment period.

Then, different assumptions characterise the different scenarios from 2020 onwards. Let us now briefly explain all the scenarios. Note that scenarios 2 to 7, chosen to cover both optimistic and pessimistic predictions on future abatement targets, have already been discussed in greater detail in Buchner and Carraro (2005). In particular, using the integrated climate-economy model FEEM-RICE, the six different scenarios on future emission abatement commitments have been analysed to provide an assessment of their implications for the economy. However, given the different scope of this paper, we will briefly recall their main features in order to enable a comprehensive background to our analysis.

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[5] We denote by Annex B_{-US} the countries listed in the Annex B of the Kyoto Protocol without the participation of the United States.

[6] After ratification by the Russian government and the Parliament, on November 4th, President Putin signed a bill confirming Russia's ratification of the Kyoto Protocol, removing thus the last barrier for its entry into force as the ratification papers could be sent to the United Nations Reported by Associate Press, see http://hosted.ap.org/dynamic/stories/R/RUSSIA_KYOTO_PROTOCOL?SITE=WAOLY&SECTION=HOME&TEMPLATE=DEFAULT

[7] The Kyoto Protocol imposes absolute reduction targets, i.e. a reduction of absolute GHG emissions by a specified percentage.

[8] In order to replicate the US strategy as precisely as possible, our model computes the –18% intensity reduction by 2010 compared to the year 2000. Climate policy in terms of emission intensity targets is typically expressed as percentage reductions from some base year level. In the US context, greenhouse gas intensity is given by the ratio of greenhouse gas emissions to economic output. For a detailed discussion of the US proposal, see for example De Moor et al. (2002), Goulder (2002), Viguier (2002).

The **second scenario** assumes a continuation of the current situation. After the US announced its defection from the Kyoto Protocol in March 2001, the remaining Kyoto countries – in particular the EU and Japan – put great effort into the continuation of the Kyoto process, in particular by convincing Russia to participate in the Protocol. This scenario assumes that the targets embedded in the Kyoto Protocol can be reached at the end of the first commitment period, as a consequence of Russia's ratification and the subsequent entry into force of the treaty. Then, the Annex B_{-US} countries decide to maintain their initial Kyoto targets and thus the corresponding emission level until the year 2100, whereas the US remains out of the Kyoto Protocol and implements no effective climate policy. This scenario thus represents the situation in which the Annex B_{-US} countries behave according to the "Kyoto forever" hypothesis, whereas the US and the developing countries have no binding emission constraints. It is assumed all countries adopt cost-effective environmental policies, and in particular, emissions trading takes place among the Annex B_{-US} countries.

In the **third scenario** we assume that, given international and domestic political pressures, the US decides to join the group of countries committed to the Kyoto Protocol in the second commitment period and afterwards. Continuity with Kyoto could be attractive for the countries that are already engaged in the Kyoto Protocol, i.e. the Annex B_{-US}, since these countries have already made a substantial investment in the Kyoto process (Bodansky, 2003). Developing countries, as in "Kyoto forever", are assumed not to adopt any emission target until 2050. Consequently, emissions in Annex B countries will be stabilised at about –5% w.r.t their 1990 value, whereas emissions in developing countries will keep growing.

Common assumptions characterise the second commitment period (2010-2020) of scenarios 4-7. International and domestic pressures for climate change control are expected to induce countries to further strengthen their efforts in international climate policy. In particular, both the remaining Annex B countries and the US are assumed to agree by 2020 to reduce emissions by an additional 10% compared to the level of emissions achieved in 2010.[9] The –10% objective for developed countries was indicated as the most likely one for the second commitment period by a panel of 44 experts interviewed by Böhringer and Löschel (2003). In order to account for the need for developing countries to continue their economic and social development, and to catch up with the industrialised world, developing countries are still exempt from complying with emission reduction targets. This assumption is also in line with recent

[9] When evaluating the economic implications of likely scenarios for the second commitment period, Böhringer and Löschel (2003) find that the global adjustment costs to accomplish the Post-Kyoto target of a 10% reduction in world carbon emissions (in their case with respect to the business-as-usual emissions in 2020) are likely to be moderate due to comprehensive "where-flexibility". Frankel (2002) also advocates small additional emission cuts for the Annex B group in the second budget period in order to go towards the broader, long-term target of worldwide average of conversion to a common formula for per-capita emissions.

research studies which conclude that it is unlikely developing countries will be included in international climate change control agreements before 2020[10].

In the **fourth scenario**, therefore, the Annex B_{-US} countries achieve the Kyoto target in the first commitment period and the –10% target (w.r.t. 2010 emissions) in the second one. The US adopts its –18% intensity target in the first commitment period and the –10% absolute target (w.r.t. 2010 emissions) in the second one. Developing countries do not commit to any emission reductions. After 2020, we assume that cooperation on climate change control collapses and emissions return to their business-as-usual (BAU) paths.

The **fifth scenario** is based on the idea that Kyoto targets are largely sub-optimal – i.e. the incentives to reduce carbon emissions should be great enough to reach more ambitious targets – and that countries are only likely to adopt targets closer to the optimal ones in the medium term. The two initial commitment periods stay the same as in scenario 4. Then, after 2020, Annex B countries (including the US) and developing countries adopt what we call "enhanced permanent cooperation emission targets", computed as follows. All countries cooperatively maximise their joint welfare with respect to their policy variables, including GHG emissions. This yields the optimal path of GHG emissions in all world regions, as it represents the cooperative outcome to all nations. Then, on the basis of the precautionary principle and given the relatively low emissions reduction in their optimal strategy, all countries pledge to reduce their emissions by an additional 10% below the optimal emission trajectories from 2020 onward.

The **sixth scenario** starts from the same premise as the previous one, namely that serious emission reductions are essential. Indeed, starting from 2020, the so-called Kyoto countries – Japan, European Union and Russia – are supposed, by 2050, to have achieved a total reduction in GHG emissions of –70% with respect to their 1990 emissions. This target is based on the recommendations of several politicians regarding the dangers of climate change. For example, the English Prime Minister Tony Blair has proposed to aim at a 60% cut in carbon emissions by 2050, thus implementing an emission reduction target of –10% for each decade, and he has advocated this target for all industrialised countries. [11] A few days after Blair's statement, the French President Chirac also echoed Blair's proposal and insisted on a strong commitment to reduce GHG emissions. In a recent announcement, the European Council re-affirmed this intention, although the ambitious goal has not yet been supported by an agreed

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[10] For example, expert judgements presented in Böhringer and Löschel (2003) reveal that in the second commitment period up to 2020 "…in 75% of the policy-relevant scenarios, developing countries do not commit themselves to binding targets." (p. 9)

[11] The "Speech on Climate Change" given by the British Prime Minister Tony Blair on February 24th, 2003, is available at http://www.britain-info.org/. The reduction goal is based on the outcomes of a recent report by The Royal Commission on Environmental Pollution (2000) which found that a 60% reduction by 2050 was essential if the overall goal of stabilising GHG emissions at 550 ppmv was to be achieved already by 2050.

statement[12]. The other countries – the US and the developing regions – reduce their emissions between 2020 and 2050 by –15% for each decade. These targets thus imply strong emission reductions in both the US and the developing countries. From 2050 onwards, when countries have achieved the ambitious emission levels, all nations are committed to maintaining these emission levels.

Scenarios 7, 8 and 9 are based on the common view that a stabilisation level of 550 ppmv in 2100 represents a reasonable goal, also adopted in the emission mitigation scenarios examined by the latest IPCC report (IPCC, 2001)[13]. In particular, the analysis of Working Group III in the TAR suggests that achieving the aggregate Kyoto commitments in the first commitment period can be consistent with trajectories that achieve stabilisation at 550 ppmv by the end of the century (WGIII TAR, Section 2.5.2). This concentration level also coincides with a doubling of CO2 atmospheric concentrations compared to pre-industrial levels. Stabilisation at such a level would imply a global warming of up to 3°C with a change in the mean surface temperature in the range of 1.6°C - 2.9°C by 2100[14]. This long-term goal is imposed from the second commitment period onwards, from 2020 to 2100, and is to be achieved through various means of burden-sharing.

In the **seventh scenario** we assume that all countries agree to make substantial efforts to control GHG emissions and to stabilise global GHG emissions at 550 ppmv in the year 2100[15]. As indicated, this concentration goal is often used as a baseline hypothesis for models examining climate sensitivity. We assume linear convergence to 550 ppmv in 2100, starting in 2020. Again, the two initial commitment periods are designed as in Scenario 4. From 2020 onwards, targets are calculated to achieve the 550 ppmv stabilisation goal. This global target is allocated among the different world regions according to the "sovereignty" equity rule, as suggested by 44 experts (Cf. Böhringer and Löschel, 2003). This rule requires that the emission entitlements are shared in proportion to emissions and thus reflects the so-called "polluter-pays principle", indicating that individual countries are responsible for their own contribution to global warming. Therefore, the emission targets for 2030, 2040 and 2050 for all world

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[12] The 25 ministers agreed on March 23 2005 that developed nations should pursue cuts of heat-trapping gases of 15-30 percent by 2020 and 60-80 percent by 2050 compared with levels set in the Kyoto Protocol, which uses 1990 as a base in most cases. But the longer-term 2050 goal has been omitted from an agreed statement. See http://today.reuters.co.uk/news/newsArticle.aspx?type=topNews&storyID=2005-03-23T173026Z_01_CHA362845_RTRUKOC_0_ENVIRONMENT-EU-CLIMATE.xml

[13] The target of not exceeding the 550 ppmv concentration level is also supported by the EU. The first significant EU proposal for a climate target for the post-2000 period, presented at the EU Council of Ministers in 1996, suggested stabilising the atmospheric concentrations of CO2 at a level around twice the pre-industrial level of about 280 ppmv, corresponding thus to the concentration target of 550 ppmv.

[14] In this range, although the strongest effects of climate change can be prevented, potentially serious damage attributable to climatic changes could still occur.

[15] Parts per million by volume is a measure of concentration of gases in the atmosphere.

regions, including developing countries, are based on both the 550 ppmv stabilisation goal and the sovereignty rule.

The **eighth scenario** is based on the so-called *Brazilian Proposal*, made for the first time by Brazil during the negotiations on the Kyoto Protocol. The idea is to allocate the emissions reductions of the industrialised, Annex I Parties in relation to the relative effect of a country's historical emissions on global temperature increase (UNFCCC, 1997). We use this approach as suggested by RIVM (Cf. den Elzen et al., 1999), i.e. the Brazilian Proposal is applied on a global level, combined with a threshold for participation for the non-Annex I regions. In particular, the stabilisation of atmospheric concentrations at 550 ppm in 2100 is achieved through burden sharing based on the contribution to temperature increase, combined with an income threshold for participation of the non-Annex I regions. This participation threshold is chosen as a percentage of the 1990 PPP Annex I per capita income.

The **ninth scenario** applies an allocation concept proposed by the Global Commons Institute, the so-called *Contraction & Convergence* approach (Meyer, 2000), to stabilise atmospheric concentrations at 550 ppm in 2100. This burden-sharing rule is also known as the Per Capita Convergence (PCC) approach and defines emission permits on the basis of a convergence of per capita emissions under a contracting global GHG emission profile. In such a convergence regime, all countries participate in the climate regime with emission allowances converging to equal per capita levels over time.
The last two scenarios take into account the immense dangers embedded in a potential climate change. They are thus derived from the scientific perspective of climatologists who claim that strong emission reductions are required in order to halt the threat of global warming.

In particular, the **tenth scenario** is based on the aim to stabilise CO2 concentrations at 450 ppmv by 2100. This emission reduction target is in general considered to be quite stringent, because it limits global mean warming to less than 3°C (see e.g. the analysis by the Working Group III in IPCC, 2001). Indeed, such a stabilisation is supposed to significantly reduce or even avoid many of the impacts listed for 3°C warming or more, enabling thus much higher benefits than a stabilisation at lower levels.[16] We assume linear convergence to 450 ppmv in 2100, starting in 2020.

The final **scenario**, number **11**, follows recent claims that the attention on the stabilisation of atmospheric GHG concentrations is not enough to solve the dilemma of climate change. Instead, one needs to go beyond the focus on concentrations by setting specific climate or radiative forcing targets (cf. Sarofim et al, 2004; Kemfert et al, 2004; Tol, 2004). According to the IPCC (2001), radiative forcing is the change in the balance between radiation coming into the atmosphere and radiation going out. The term "radiative forcing" has been employed to denote an externally imposed perturbation in the radiative

[16] Note, however, that there would still be risks for impacts associated with mean warming of less than 3°C.

energy budget of the Earth's climate system. On average, a positive radiative forcing tends to warm the surface of the Earth while a negative forcing tends to cool the surface[17]. Changes in the radiation budget can thus lead to changes in climate parameters, resulting thereby in a new equilibrium state of the climate system. The policy scenario that we adopt in this context is to stabilise radiative forcing at 4.5 Wm^{-2} relative to pre-industrial times by 2100[18]. This target is quite ambitious, and corresponds roughly to an equilibrium temperature of 3°C by 2100, inducing substantial emission reductions.

Table 1 provides a comprehensive summary of the main features of the 11 scenarios.

4. Discussion of results and conclusions

This paper has aimed to investigate DEA methodology as a tool for comparing and more comprehensively evaluating climate policies. Let us now discuss the main findings.

The results of the DEA-based CBA are summarised in Table 4 and Table 5. First, we performed the analysis considering unconstrained domains for the two weights (prices) related to impact on the environment and on society. Starting from the assumption that either the environmental or the social impacts or even both of them could be ignored in the valuation, still seven out of the eleven scenarios in consideration cannot be put aside but have to go through further analysis (see Table 4). If we instead assume that *each* of the two non-economic impacts has to play some – even if a very small – role, then a constrained analysis has to be performed and the deriving results are summarised in Table 5. In particular, we see that only three out of the eleven scenarios have a non-negative value of comparative advantage, and they are the "Kyoto Forever without US", the "Enhanced permanent global cooperation" and the "550ppmv through Contraction & Convergence" scenarios.

Let us explore these findings in more detail. The first scenario, "Kyoto Forever without US", is characterised by only a slight comparative advantage. Still, this result is striking as it indicates that the continuation of the current path in climate policy, i.e. moderate efforts by a subset of countries, can be

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[17] Potential perturbations can be induced by secular changes in the concentrations of radiatively active species (e.g., CO_2, aerosols), changes in the incidence of solar irradiance upon the planet, or other changes that affect the radiative energy absorbed by the surface (e.g., changes in surface reflection properties). For a more detailed discussion see e.g. IPCC (2001).

[18] Recently, this stabilisation target has become a new focus and quite a common research topic. For example, one of the objectives of the EMF 21 Working Group is to conduct a new comprehensive, multi-gas policy assessment to improve the understanding of the effects of including non-CO2 GHGs and sinks into short- and long-term mitigation policies. In this context, a new long-term, CO2-only stabilisation scenario is investigated in order to evaluate the significance of multigas mitigation (including sinks). The relevant emissions target consists in the stabilisation of the radiative forcing at 4.5 Wm-2 relative to pre-industrial times by 2150, holding the radiative forcing from non-CO2 GHGs constant at the 2100 level. See, for example, Tol (2004) and Kemfert et al. (2004).

considered as a strategy that enables a good economic performance, whilst maintaining comparatively acceptable environmental and social impacts. The second scenario, “Enhanced permanent global cooperation”, already has a quite significant comparative advantage. This result appears to be important for the future evolution of climate policy, as it implies that deriving future emission reductions from countries’ optimal abatement strategies, and imposing moderate targets on *all* countries, including the developing countries, can be advantageous from a sustainability point of view. This scenario is thus attractive both for the single countries and for the overall goal of sustainable development. The final scenario, “550ppmv through Contraction & Convergence”, provides a very large comparative advantage. This result can be considered as being striking, given that it again includes the participation of all countries with per capita emission allowances converging towards equal levels over time. The approach combines stabilisation at a reasonable level of atmospheric concentrations with a strategy that appears to be rational for all countries. While costly in terms of impact on global gross output, the scenario comparative advantage derives from its extremely beneficial environmental and social implications.

Moreover, to further discriminate among policies, it can be extremely useful to analyse the DEA-based CBA results in the prices space. As an example, let us concentrate on the scenario “Kyoto Forever without US”. Figure 6 shows how comparative advantage of the considered scenario changes, given the entire range of prices of the environmental impact (p_e) and of the social impact (p_s), expressed in dollar per index number. Analogously, surfaces corresponding to each of the policy scenarios can be added to the graph, then, given the coordinates corresponding to an estimate or a subjective judgment of prices, representing different dimensions of sustainability, it will be possible to see which of the policies prevail. This type of analysis provides the decision maker with a more complete and general set of information, which can provide the stimulus and the quantitative basis for subsequent political and ethical debate.

Results derived from the traditional DEA analysis are presented in Tables 6 and 7. A policy is rated as fully (100%) efficient on the basis of available evidence if and only if the performances of other policies do not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs. Table 6 provides the results for a cost minimisation model with constant returns to scale. As it happens, efficiency measures appear to be similar, making it difficult to pinpoint the existing differences between policies. This is a numerical problem, partly due to the limited set of policies in the analysis. In order to overcome this problem and to better distinguish between policies, we introduce an artificial policy, which we refer to as the ‘optimal scenario’, which is a virtual policy composed taking, for any indicator, the best score in the sample. Results of this second analysis are presented in Table 7, where it is possible to better discriminate among scenarios. “BaU” and “550ppmv through Contraction & Convergence” scenarios appear to be the most efficient in this analysis (of course this is also true for ‘perfect scenario’, by construction). The first result, i.e. the positive performance of the business-as-usual case, seems to be logical from a cost minimisation perspective. Indeed, as expected, no commitment to climate change control leads to the best outcome in terms of avoided expenditures. The more striking finding regards again the "550ppmv through Contraction & Convergence" scenario. This policy architecture confirms the good performance obtained in terms of sustainability. As a consequence, this approach seems to be very promising for future negotiations on climate change control. At the same time, it is possible to get information concerning potential improvements for other scenarios that prove inefficient; these can be derived from the comparison of the inefficient policy with the nearest efficient policies, or peer group. Therefore, corrective measures can be designed in order to reshape partially flawed policy structures.

Summarising, this paper has applied an innovative method based on the coupling of an integrated climate-economy model with the Data Envelopment Analysis methodology to evaluate a range of climate policy scenarios. The analysis has provided some information on the relative efficiency of different policy lines. In particular, it has been shown that the inclusion of all world countries in the international climate change efforts can be advisable both from a sustainability and a cost minimisation perspective. Indeed, the scenario that aims, by 2100, to stabilise CO2 concentrations at 550 ppm by including all world countries according to the so-called Contraction & Convergence approach, is characterised by positive performances with regard to the economic, environmental and social dimensions.

However, the findings of this analysis need to be taken cautiously, because of the arbitrariness of the choice of the impacts indicators and of the choice of the simulation model. Nonetheless, the methodology in itself can represent an important tool for policy makers, through the identification of a number of policy strategies that appear to be crucial for the evolution of the future climate debate. As a consequence, the approach adopted in this paper could be extremely beneficial if combined with different types of climate-economy models and different choices of costs and benefits indicators.

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Table 1: An overview on the alternative policy architectures			
Expected Emissions			
	2010	2020	from 2020 onwards
Scenario 1 "BAU - Business-as-Usual"			
Annex B_{-US}	"Business-as-Usual"		
US			
Developing countries			
Scenario 2 "Kyoto Forever without US"			
Annex B_{-US}	Kyoto target: -5.2%	2010 level	2010 level
US	-18% intensity target	business-as-usual	business-as-usual
Developing countries	business-as-usual	business-as-usual	business-as-usual
Scenario 3 "Kyoto Forever without US only in the first commitment period"			
Annex B_{-US}	Kyoto target: -5.2%	2010 level	2010 level
US	-18% intensity target	Kyoto constraint	2020 level
Developing countries	business-as-usual	business-as-usual	business-as-usual
Scenario 4 "Annex B cooperation only until 2020"			
Annex B_{-US}	Kyoto target: -5.2%	-10%	"Business-as-Usual"
US	-18% intensity target	-10%	
Developing countries	business-as-usual	business-as-usual	
Scenario 5 "Enhanced permanent global cooperation"			
Annex B_{-US}	Kyoto target: -5.2%	-10%	"Enhanced cooperation"[1]
US	-18% intensity target	-10%	
Developing countries	business-as-usual	business-as-usual	
Scenario 6 "-70% emission target"			
Annex B_{-US}	Kyoto target: -5.2%	-10%	-70% emission target in
US	-18% intensity target	-10%	-15% each decade
Developing countries	business-as-usual	business-as-usual	
Scenario 7 "Stabilisation at 550 ppmv"			
Annex B_{-US}	Kyoto target: -5.2%	-10%	Stabilisation at 550 ppmv in 2100 with emission targets allocated according to sovereignty rule
US	-18% intensity target	-10%	
Developing countries	business-as-usual	business-as-usual	
Scenario 8 "550ppmv through the RIVM's Brazilian Proposal"			
Annex B_{-US}	Kyoto target: -5.2%	Stabilisation at 550 ppmv in 2100 with emission reductions allocated according to the Brazilian Proposal combined with threshold for non-Annex I regions	
US	-18% intensity target		
Developing countries	business-as-usual		

Scenario 9 "550ppmv through Contraction & Convergence"		
Annex B_{-US}	Kyoto target: -5.2%	Stabilisation at 550 ppmv in 2100 with emission reductions allocated according to C&C Approach: All Parties participate immediately in the climate regime with per capita emission allowances converging towards equal levels over time.
US	-18% intensity target	
Developing countries	business-as-usual	
Scenario 10 " Stabilisation at 450 ppmv "		
Annex B_{-US}	Kyoto target: -5.2%	Stabilisation at 450 ppmv in 2100
US	-18% intensity target	
Developing countries	business-as-usual	
Scenario 11 "Radiative Forcing"		
Annex B_{-US}	Kyoto target: -5.2%	Stabilisation of radiative forcing at 4.5 Wm–2 relative to pre-industrial times by 2100
US	-18% intensity target	
Developing countries	business-as-usual	

[1] Targets deduced from the optimal cooperative intertemporal solution of the dynamic game among countries and strengthened by requiring an additional –10 % reduction.

Table 2: An overview on the cost and benefit indicators	
Social Indicator	
Equity Index:	$EI = \frac{EY}{AY}$ where EY stands for equivalent income, AY for average income and where EY is: $EY = \exp\left[\sum_{n \in N} pop\_share(n) * \log(NetGDP)\right]$ Distance from maximum attained equity value
Environmental Indicator	
Temperature	Measured in (deg C) above pre-industrial levels. Distance from a target of 2 deg C
Economic Indicators	
Production	Global Discounted Output (1995-2105), measured over the eight macro regions, in 1990 USD.
R&D expenditures	Global Discounted R&D Expenditures (1995-2105), measured over the eight macro regions, in 1990 USD

Table 3: An overview on the cost and benefit indicators
Benefit Indicators
Equity Index (in absolute value)
Global Discounted Output (1995-2105) in 1990 USD
Global Discounted Consumption (1995-2105) in 1990 USD
Cost Indicators
Global Discounted R&D Expenditures (1995-2105) in 1990 USD
Temperature (deg C) above pre-industrial level (absolute value)

Table 4: Results of DEA-based CBA. No bounds on both prices

	CA	**Pe**	**Ps**
Scenario 1	-0.01	0.00	0.00
Scenario 2	**0.12**	**7.30**	**0.00**
Scenario 3	-0.06	2.47	5.93
Scenario 4	**0.03**	**2.47**	**0.00**
Scenario 5	**1.96**	**13.64**	**5.42**
Scenario 6	**0.11**	**17.14**	**1.47**
Scenario 7	**0.21**	**39.33**	**3.41**
Scenario 8	**1.79**	**92.16**	**0.00**
Scenario 9	**19.88**	**0.00**	**13.87**
Scenario 10	-0.16	35.62	3.08
Scenario 11	-0.15	17.88	1.53

Table 5: Results of DEA-based CBA. Lower and Upper Bounds on both Prices, $P_e \in [5, 150]$; $P_s \in [5, 150]$.			
	CA	Pe	Ps
Scenario 1	-0.13	5.00	5.00
Scenario 2	**0.07**	**5.00**	**5.00**
Scenario 3	-0.06	5.00	5.00
Scenario 4	-0.07	5.00	5.00
Scenario 5	**1.96**	**13.64**	**5.42**
Scenario 6	-1.17	5.00	5.00
Scenario 7	-0.92	27.25	5.00
Scenario 8	-2.27	27.25	5.00
Scenario 9	**230.93**	**150.00**	**150.00**
Scenario 10	-1.80	27.25	5.00
Scenario 11	-2.16	20.00	5.00

Table 6: Results of the Cost Minimising Constant Return to Scale Model	
Unit	Score
Scenario 8	**100,00**
Scenario 9	**100,00**
Scenario 2	**100,00**
Scenario 4	**100,00**
Scenario 5	**100,00**
Scenario 1	**100,00**
Scenario 3	99,26
Scenario 6	94,87
Scenario 10	94,60
Scenario 7	93,23
Scenario 11	92,47

Table 7: Results of the Cost Minimising Constant Return to Scale Model, with Perfect DMU	
Unit	**Score**
Scenario 9	**100,00**
Scenario 1	**100,00**
Perfect	**100,00**
Scenario 4	99,69
Scenario 2	98,60
Scenario 3	97,79
Scenario 5	89,79
Scenario 7	86,54
Scenario 8	83,52
Scenario 11	81,33
Scenario 10	79,76
Scenario 6	78,43

Figure 1: Economic indicator for different scenarios: Global Discounted Output (1995-2105) in 1990 USD

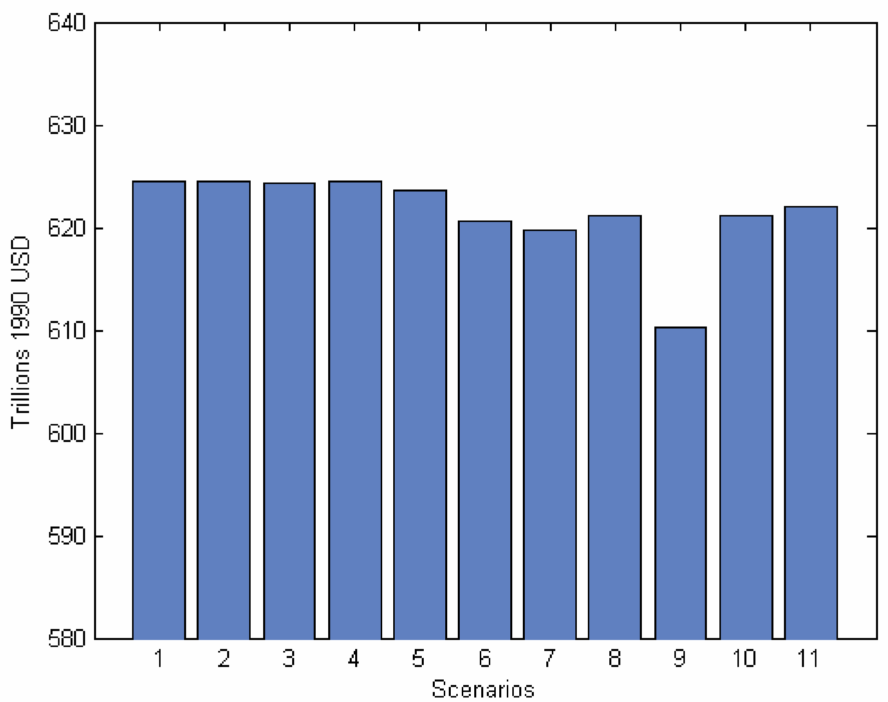


Figure 2: Economic indicator for different scenarios: Global Discounted R&D Expenditures (1995-2105) (trillions 1990 USD)

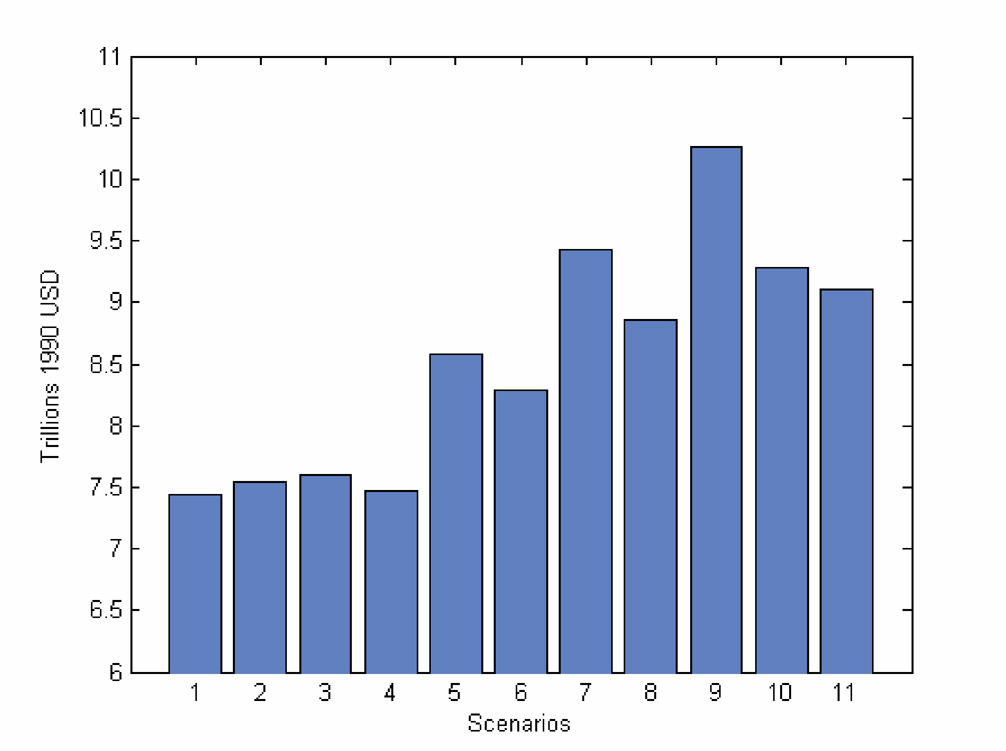


Figure 3: Environmental indicator for different scenarios: Global CO2 Atmospheric Temperature in 2105 in deg C above pre-industrial levels

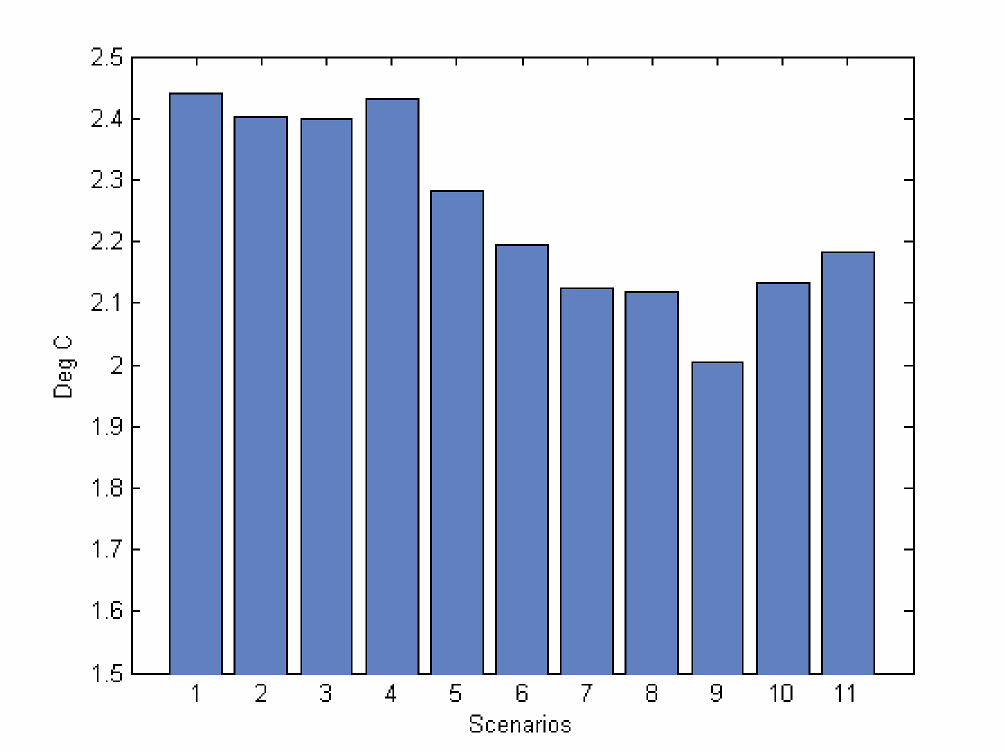


Figure 4: Social indicator for different scenarios: Equity Index

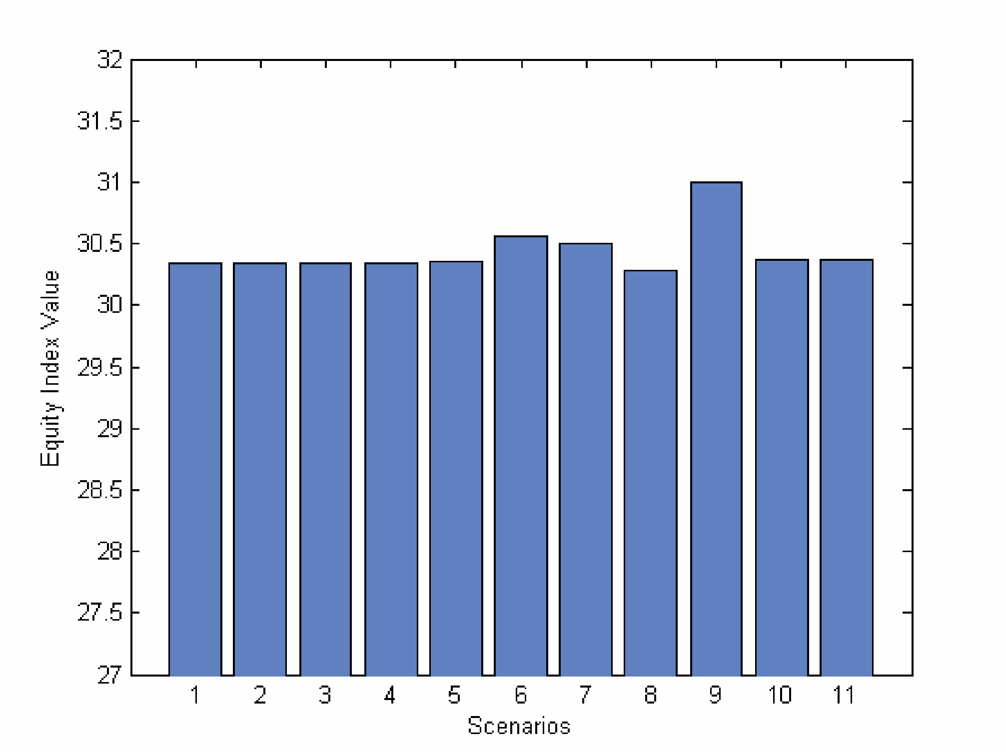


Figure 5: Economic indicator for different scenarios: Global Welfare (trillions 1990 USD)

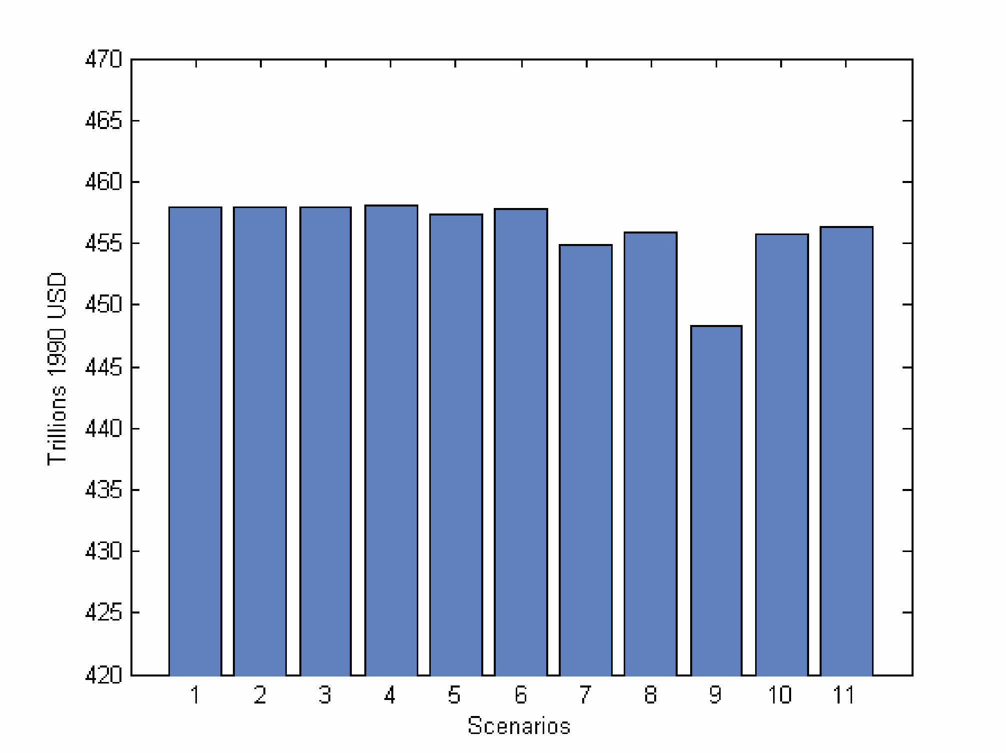
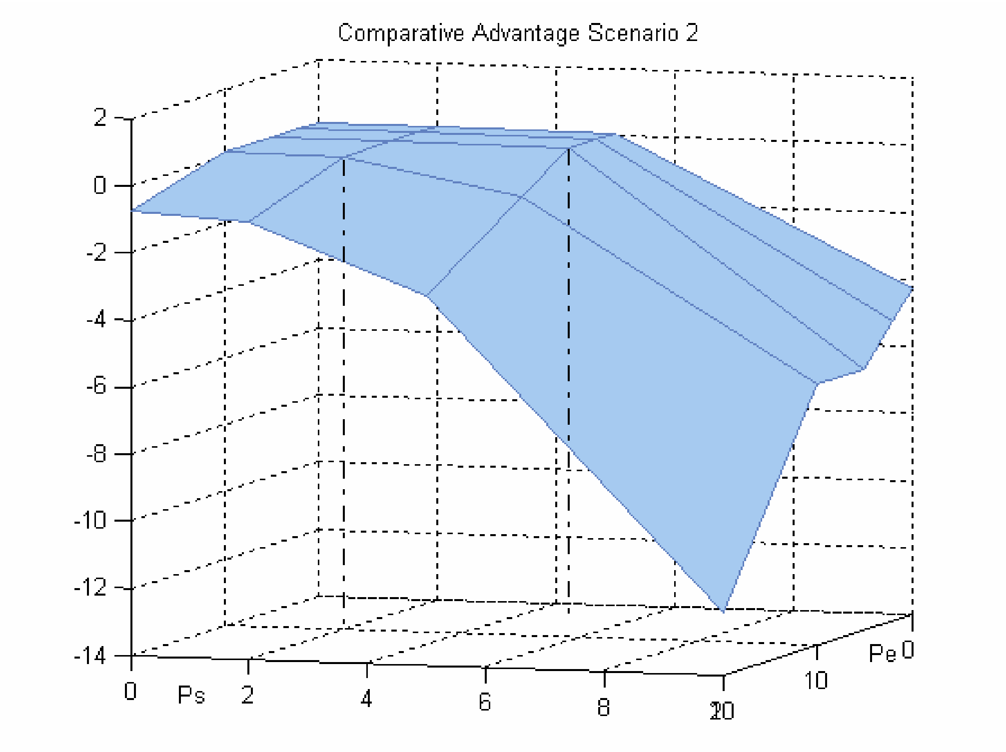


Figure 6: Comparative Advantage of Scenario 2 in the price space (P_e, P_s)



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(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003

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(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003

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(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

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(lxxii) This paper was presented at the 10th Coalition Theory Network Workshop held in Paris, France on 28-29 January 2005 and organised by EUREQua.

(lxxiii) This paper was presented at the 2nd Workshop on "Inclusive Wealth and Accounting Prices" held in Trieste, Italy on 13-15 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics

(lxxiv) This paper was presented at the ENGIME Workshop on “Trust and social capital in multicultural cities” Athens, January 19-20, 2004

(lxxv) This paper was presented at the ENGIME Workshop on “Diversity as a source of growth” Rome November 18-19, 2004

(lxxvi) This paper was presented at the 3rd Workshop on Spatial-Dynamic Models of Economics and Ecosystems held in Trieste on 11-13 April 2005 and organised by the Ecological and Environmental Economics - EEE Programme, a joint three-year programme of ICTP - The Abdus Salam International Centre for Theoretical Physics, FEEM - Fondazione Eni Enrico Mattei, and The Beijer International Institute of Ecological Economics

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